Management of Irradiated and Contaminated Casualty Victims

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Perhaps nothing in modern technology incites greater fear than the thought of a radiation accident. Media coverage of the Three Mile Island nuclear power reactor accident and fictional portrayals such as the motion picture "The China Syndrome" have created in the minds of most people an absolute horror of the thought of radiologic accidents. However, a closer examination of the record indicates the relative safety with which nuclear power and radiation have been managed. Three Mile Island, rather than demonstrating the dangers of nuclear power, should serve to illustrate the safety designed into power reactors through their interlocking safeguard systems. Three Mile Island represents the most serious accident to date involving the commercial nonresearch use of nuclear power and yet absolutely no injuries were incurred as a result of that accident. The United States Navy has developed a record of over 1000 reactor years of operation with nuclear reactors without an accident. Even the transportation industry has an enviable record in the safe transportation of radioactive materials when compared with transportation of other hazardous materials. Almost weekly an incident of leakage, spillage, or release of hazardous chemicals can be found somewhere in the news. This is not to suggest, however, that the possibility of a radiation accident does not exist. The possibility is very real and all medical facilities should be prepared to manage such accidents. Hospitals and other medical care facilities in the vicinity of nuclear power plants, radiologic laboratories, or nuclear material processing plants and hospitals with large nuclear medicine departments normally will have a standard radiation accident protocol in place. However, even those hospitals that are isolated from such facilities should be prepared to manage the incidental radiation accident that may occur. Such an accident may occur

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within the hospital's own radiology or nuclear medicine department or as a result of the transportation of radioactive materials in their vicinity. Such accidents, although most certainly involving only one or a small number of casualty victims, may well involve other traumatic injury to the victims. It is this situation that this article is primarily intended to address.

RISK

A better understanding of the potential hazards associated with nuclear power and radiation sources can be derived by comparing those risks with the risks of other "accidents." Table 1 indicates the chance of serious injury or death per year for a variety of potential accidents. Note that the risks associated with nuclear reactor operation are fleetingly small; in fact they are smaller than the risk of radiation cancer derived from a single round trip airplane flight from New York City to San Francisco and back. It has been estimated that the risk of death as a result of nuclear power to the average person in the United States is approximately equal to the risk of dying by being struck by a meteor. Neither of these risks is actually measurable because no good data exist on which to base them. Table 2 indicates the average annual exposure of the United States population to radiation from a variety of sources. Note once again that exposure to radiation from nuclear power plants is fleetingly small compared with naturally occurring radiations and diagnostic x-rays. Even radiation exposure occurring as a result of fallout from weapons testing is small compared with these sources, and as long as atmospheric weapons testing does not take place, it gets smaller each year. Placed in this perspective, it is apparent that the overall risk associated with nuclear power or radiation accidents is quite small relative to other risks commonly occurring to the population.[2] Recent studies suggest that even the risk of psychological stress resulting

Table 1. *Annual Probability of Serious Injury or Death**

Auto accident (disability)	1 in 100
Smoking mortality	1 in 175
Cancer	1 in 700
Auto accident (death)	1 in 4000
Air pollution	1 in 10,000
Fire	1 in 25,000
Birth control pill (death)	1 in 25,000
Drowning	1 in 30,000
Shooting	1 in 50,000
Electrocution	1 in 200,000
Round trip air flight New York to San Francisco (radiation cancer risk)	<1 in 1,000,000
Reactor radiation exposure at site boundary	<1 in 1,000,000
Reactor radiation exposure within 50 mile radius	<1 in 10,000,000

*Adapted from Radiation Biology for Corpsmen 8402/07. Naval Undersea Medical Institute, Naval Submarine Base, New London, Groton, Connecticut.

Table 2. *Annual Radiation Exposure of United States Population**

SOURCE	AVERAGE DOSE (Mrem/year)
Natural background	100–150
Diagnostic x-ray	50–150
Permissible exposure (population average)	170
Weapons testing	3
Air travel, luminous dials, color TV, and so forth	1
Nuclear power plants	<.001

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from radiation accidents is small compared with the daily psychological stresses that we all face.

RADIATION PHYSICS

To understand the effects of radiation, one must have a basic knowledge of the types and sources of radiation. Radiation may occur as an emanation from the nucleus of a spontaneously decaying, naturally occurring radioisotope. Radiation may also be produced artificially as a result of beaming a stream of highly energetic electrons against a target, the result being the production of x-rays, or from artificially produced radionuclides made within nuclear reactors or by special types of generators. Radiation is of two types, particulate, which consists of particles with a measurable mass with or without electrical charge, and electromagnetic, which consists of massless waves of energy "packets" termed "quanta." Electromagnetic waves have no charge. The effects caused by these radiations are determined by a combination of these three factors, namely, the mass, the electrical charge, and the speed. The energy of the radiation is also a function of these three factors.

Alpha particles are the largest of the particles, consisting of two protons and two neutrons, that is, identical to a helium nucleus. Alpha particles have a positive charge of two and generally have a high energy level. Owing to their large mass and charge and slow speed, however, alpha particles dissipate their energy very rapidly and indeed cannot penetrate the skin. Alpha particles therefore do not represent an external irradiation hazard but can be a very serious hazard as internal contamination. The beta particle, with a very small mass and a single negative charge, is equivalent to an electron. Positively charged beta particles are also possible but need not be considered for our purposes. With their smaller mass and charge and greater speed, beta particles will penetrate somewhat deeper than alpha particles and can represent an external radiation hazard, particularly to the skin. However, they represent a greater hazard when deposited internally than they do with external exposure.

The neutron is a particle having a moderate mass, no charge, and various speeds. Neutrons are unlikely to be encountered except in direct relation to an operating nuclear reactor. The neutron does not ordinarily represent an internal radiation hazard but can be an external hazard. Neutrons do have the property, however, of inducing radiation within material exposed to a neutron flux. Therefore, exposure to neutrons can result in production of radioactivity within the body or cause direct damage.

Electromagnetic radiation has no mass or charge; it travels at the speed of light and consists of energy packets called quanta. Ionizing electromagnetic radiation is the high energy end of the continuous spectrum of electromagnetic radiation, which includes microwaves, infrared waves, visible light, and ultraviolet radiation. These radiations are known as nonionizing and are distinguished from the ionizing radiations only by the fact that the energy contained within the quanta is insufficient to create an ionization on interacting with matter. The distinction between nonionizing and ionizing electromagnetic radiation is at just over 30 electron volts, the average energy required for ionization. Ionizing electromagnetic radiation consists of gamma rays and x-rays that are essentially indistinguishable except as regards their source. Having no mass or charge, ionizing electromagnetic radiations are extremely penetrating and represent primarily an external hazard. Their primary effect is to cause the ejection of electrons from atoms with which they interact. These electrons then act as secondary particles to produce additional ionization.[5]

INTERACTIONS OF RADIATION WITH MATTER

Although different types of radiation may have different primary interactions at the atomic level, when they pass through matter, the ultimate result is to produce ionization within the matter. The precise primary interactions are irrelevant for our purposes. It is the resulting ionization that is significant. The ionizations occur by the ejection of an electron from an atom, resulting in a positively charged atom and a negatively charged electron, which, if energetic enough, may itself cause additional ionizations as it passes through the matter until it comes to rest. At that point it is absorbed by another atom or ion. The rate at which radiation deposits its energy as it passes through matter is known as the linear energy transfer. The linear energy transfer varies directly with the mass and charge and inversely with the energy of the radiation. Higher mass or charge or lower energy radiation causes a larger number of ionizations per unit of track length than does radiation with less mass or charge or more energy. The effects of radiation on living matter result from ionizations occurring within the system and are determined to some extent by the relationships involved in the linear energy transfer. This function of ionization also permits the measurement of radiation.[5]

RADIATION DOSIMETRY

Measurement of radiation is basically of two types that are interrelated both physically and mathematically. Measurement may be made of the instantaneous radiation level at a point at a given time, the flux, or may be made of the total amount of radiation exposure or absorption in a system. Two different systems are used to make measurements of each type. Radiation flux is measured with devices that are termed "dose rate meters." A classic example of a dose rate meter is a Geiger-Müller tube or "Geiger counter." Other meters in this category may use scintillation crystals. This type of meter normally reads the dose in amount of radiation per unit of time. Radiation measuring systems that measure radiation exposure or absorbed dose are usually used in personnel dosimetry programs. The classic example of this type of system is the film badge dosimeter in which ionizations cause a darkening of the photographic emulsion on the film. In this manner, the total amount of radiation absorbed by the film is measured by the increased density of the film. Other dosimeters of this type are the thermoluminescent dosimeter and the pencil type of pocket dosimeter. This type of dosimeter usually provides a measurement integrated over a longer period of time and indicates the total amount of radiation absorbed during that time period.[3, 5]

Radiation Units

The roentgen (R) is a unit of exposure to x-rays or gamma rays. As defined, the roentgen is equivalent to the deposition of approximately 87 ergs of energy per gram of air. Radiation absorbed dose (rad) is used with any type of radiation in any material and is defined as the deposition of 100 ergs of energy per gram of material. For most general working purposes, a roentgen is considered to be equivalent to 1 rad. The roentgen equivalent man (rem) is a dose equivalent used to express the effects of absorbed dose of any type of radiation in humans. It is determined by multiplying the dose in R or rads by a quality factor (QF). Quality factors vary from 1 for x-rays, gamma rays, and most beta rays to 20 for naturally occurring alpha particles. The rem is used in radiation dosimetry programs for occupationally exposed personnel. This will most often be seen as millirem (mrem) or 0.001 rem because doses at the rem level are rarely seen.[3]

Permissible Radiation Exposure Levels

The annual average permissible exposure level across the entire United States population has been set by the National Council on Radiation Protection (NCRP) at 170 mrem. This does not include natural background or medical diagnostic or therapeutic radiation. This is approximately two orders of magnitude higher than that actually occurring. The permissible exposure for workers occupationally exposed to ionizing radiation is 5 rem per year. The vast majority of exposures actually recorded do not exceed one-tenth of that amount. It has also been established by the NCRP that a once-in-a-lifetime exposure of 100 rem for purposes of saving a life is acceptable and will result in no undue morbidity. Permissible doses of internally deposited radioisotopes are based on the total amount of radiation that will be delivered to the body. These levels are termed "maximum permissible body burdens."[2, 3, 9]

BIOLOGIC EFFECTS OF RADIATION

The biologic effects of radiation occur as a result of effects at the cellular level. These may be cell death or modification of the structure or function of the cell to the extent that it cannot carry out its normal activities or, indeed, that it may function abnormally with loss of normal controls, as, for example, with cancer. The critical target molecule within the cell is the DNA. The DNA may be affected by direct action of the radiation on the DNA molecule. It is much more likely, however, that the radiation will interact with water molecules, which constitute 80 per cent of the cell. As the water molecules are ionized, they react to form free radicals such as the hydrogen or hydroxyl radicals. These radicals may recombine in ways to produce molecular hydrogen, hydrogen peroxide, or the peroxyl (HO_2) radical. All of these species are highly reactive and when formed can react with other molecules within the cell, particularly the DNA molecule. It is most probable that the majority of effects on the cell will result from this indirect action of radiation. Although other macromolecules such as protein or carbohydrate within the cell may be affected by radiation, it is improbable that this will result in a serious adverse effect upon the cells. We may, therefore, consider the DNA molecule within the cell to be the critical target for radiation damage.[1, 3, 11]

Acute Radiation Syndrome

Acute radiation syndrome is the symptom complex that occurs when the person has been exposed to an acute whole body dose of penetrating radiation. The type of radiation is immaterial provided that it occurs as a fairly uniform whole body dose over a relatively short period of time. A substantial dose is required to produce detectable signs or symptoms of acute radiation sickness. Approximately 25 to 30 rems are required to produce detectable laboratory changes; approximately 100 rems are required to produce symptoms. The dose level at which 50 per cent of those exposed can be expected to die within 30 days (median lethal dose/30) is in the range of 400 to 500 rems.

Acute radiation syndrome is usually divided into three distinct symptom complexes. With doses of several thousand rems the central nervous system syndrome is predominant. Nausea and vomiting begin almost immediately, followed by neurologic, behavioral, and psychological changes. These proceed rapidly to prostration and coma, with death usually occurring within 24 to 48 hours.

At doses between 500 and 1000 rems, the gastrointestinal syndrome predominates. Nausea, vomiting, and diarrhea may occur promptly followed by a short latent period during which an apparent return to normalcy is experienced. This is followed by severe gastrointestinal symptoms, marked anorexia, increasing vomiting, and diarrhea with signs of infection and dehydration developing. A terminal phase with markedly severe diarrhea, vomiting, and prostration ensues, with death occurring in about five days. At the upper end of this dose range, 100 per cent mortality will occur. At the lower end, at least 50 per cent mortality is to be expected. The severity of the initial symptoms serves as a useful prognostic index; that is, the more severe the initial phase, the higher the probability of death.

At doses between 100 and 500 rems the hematopoietic syndrome occurs. Mortality is generally nil at the lower end of this spectrum but approaches 50 per cent at the upper end. It is within this range that aggressive treatment can make a significant difference in survival. The hematopoietic syndrome begins with a prodromal phase consisting of nausea, vomiting, and diarrhea. This may last for a day or two and is followed by a latent period during which the symptoms resolve and the individual feels relatively well. At the end of the second or third week, epilation may begin and infection due to the depressed white blood cell count may appear. A reduced number of platelets appearing at the same time results in hemorrhage of variable degree. At this phase of the syndrome, the individual is seriously ill. The characteristics of the acute radiation syndrome are summarized in Table 3 and Figure 1.

Treatment of Acute Radiation Syndrome. There is no emergency treatment specific to accidental radiation exposure. Although some symptomatic treatment may provide comfort during the prodromal phase of the illness, no specific therapy in these early days will make any difference in long-term survival. During this period, precise dose measurements or estimations should be obtained and verified by monitoring changes in blood components. For doses below 200 rems, probably no additional therapy will be needed and spontaneous recovery will occur. For doses in excess of 1000 rems, survival is essentially impossible and no treatment other than providing for the comfort of the victim will be of any use. For exposures falling between these levels, aggressive therapy can make a great difference in survival of the patient. There is no real urgency in taking any therapeutic action, as some time will be required for the full syndrome to develop. No therapeutic action should be taken without a clear-cut clinical indication.

Patients with exposures in the intermediate dose ranges should be promptly placed into a reverse isolation atmosphere. Only sterile supplies, food, and clothing should be used and all personnel entering the isolation area should be free of contamination or infection. A complete history and physical examination should be performed to determine the possibility of pre-existing chronic infections that may become a significant problem when the granulocyte count becomes depressed. Responsible authorities should be promptly informed. These would include state agencies, the Department of Energy Regional Coordinating Office for Radiological Assistance, and, for advice and assistance regarding patient care, the Radiation Emergency Assistance Center/Training Site (REAC/TS) Oak Ridge Associated Universities, Oak Ridge, Tennessee. REAC/TS can be contacted 24 hours a day for radiation accident assistance at (615) 576–1004.

Peripheral blood counts and bone marrow aspirations should be followed on a regular basis. Not only will this allow close monitoring of the patient's progress, but upon return of mitoses in the bone marrow aspirations, it can be assumed that regeneration of the marrow is occurring. Daily weights and inputs and outputs should be maintained. Skin and orifice hygiene should receive particular attention; these may serve as portals for entry of bacteria. Mouth care and anogenital care should be emphasized.

Table 3. *Acute Radiation Syndrome*

DOSE RANGE (rem)	SYNDROME TYPE	SYMPTOMS	LYMPHOCYTES (Day 2)	PLATELETS (Day 30)	TREATMENT	PROGNOSIS
0–25	None	None	Normal	Normal	None	
25–100	None	Mild prodromal	Normal or slightly depressed relative to base line	Normal or slightly depressed relative to base line	None necessary	
100–200	Hematopoetic (mild)	Prodromal nausea and vomiting	50% reduction	25–50% reduction	Symptomatic	Recovery expected
200–400	Hematopoetic (moderate)	Prodromal; latent period; definite hematologic derangement; some nausea and vomiting	75% reduction	50–75% reduction	Supportive antibiotics; blood products	Some mortality; most recover
400–600	Hematopoetic (severe); some gastrointestinal	Marked prodromal; latent period; marked hematologic derangement; nausea, vomiting, diarrhea; prostration; bleeding; infection	90% reduction	90% reduction	Supportive fluids; antibiotics; blood products; marrow transplants; stem cell transfusion	50% or more mortality
600–1000	Gastrointestinal	Marked prodromal; shortened latent period; marked nausea, vomiting, diarrhea; prostration; coma, death; hematologic derangement depends on survival time	Essentially absent	Essentially absent	All of above or expectant	Mortality increases to 100% above 900 rems
5000	Central nervous system	N/A	N/A	N/A	N/A	Death within 2 days

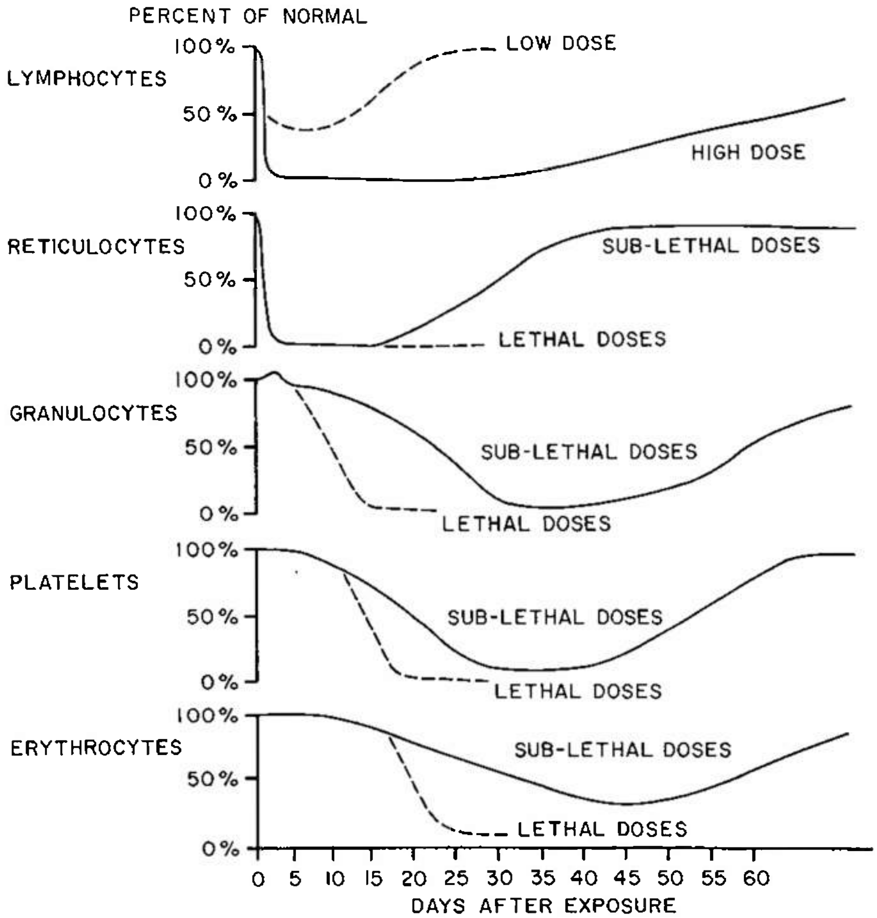

Figure 1. The blood element response to acute whole body radiation is shown.

All skin punctures should be performed with absolutely aseptic technique. Nonabsorbable intestinal antibiotics may be used to sterilize the gut and thus minimize the probability of bacterial invasion. Prophylactic antibiotics are otherwise not indicated until specific signs of infection develop, such as a sudden spike in fever or the development of ulcerations with a severely depressed leukocyte count. Cultures should be obtained prior to the initiation of antibiotics so that changes in antibiotic therapy depending on the sensitivity of the bacteria can be appropriately planned. When antibiotics are given, they should be given in massive doses two or three times the amount normally used. If fever cannot be controlled on the initial antibiotic regimen or if the temperature begins to rise again, a shift should be made to another antibiotic. During treatment with broad-spectrum antibiotics, oral antifungals should also be utilized to prevent fungal overgrowth.

A careful watch for signs of bleeding should also be maintained. At the first indication that bleeding has begun, whole blood transfusions should be started to maintain a reasonable hematocrit. Only fresh whole blood should be used. When the hematocrit is at a satisfactory level, separated platelet transfusions should be administered. For doses in excess of 500 rems, one may wish to consider the possibility of a bone marrow transplant. Such a step should probably only be taken, however, under the advice and direction of a knowledgeable authority such as REAC/TS.

In summary, then, treatment of the acute radiation syndrome consists of reverse isolation to prevent infection, bed rest, careful nursing care to prevent bleeding, aggressive antibiotic therapy to control infection when it appears, and platelet transfusion to stop bleeding. In general, however, if the patient's exposure suggests that he or she will fall into the category requiring therapy of this nature, it would perhaps be best to refer the patient to a facility designed to care for radiation accident victims such as that at REAC/TS or the Regional Radiological Assistance Offices. There would generally be ample time between the prodromal symptoms and the full blown radiation syndrome during the latent period to effect this transfer.

Local Radiation Injury

Exposure of localized areas of the body to radiation results in a vastly different injury than that of full body radiation, and much higher levels of radiation are required to produce significant injury. The best examples of local radiation injury can be found in patients undergoing radiation therapy for various types of neoplasms. The two characteristic problems that they develop are radiation dermatitis and radiation osteonecrosis, particularly necrosis of the mandible in patients undergoing head and neck irradiation. Either of these injuries requires massive local doses of radiation measuring in the thousands of rems. Neither of these injuries requires any emergency care and, indeed, neither requires specific therapy other than the normal medical and surgical procedures that would be utilized for similar injuries from other sources. These would consist of appropriate hygiene, antibiotic therapy, if necessary, and minimal surgical debridement, as needed, followed by such grafting as may be required. Recent use of hyperbaric oxygen therapy in radio-osteonecrosis of the mandible has shown great promise and should be considered if it is available.[3, 11, 12]

Late Effects of Radiation

Radiation does not produce any new or unique diseases. All observed effects are those normally seen in an aging population. Radiation serves only to increase the probability of developing a specific disease and thus to some extent can be considered to be an age accelerator. In contrast to the effects of the acute radiation syndrome, which can be rather well predicted for a specific dose level, late effects are totally unpredictable. These effects can only be observed across a large population and no determination in regard to specific individuals can be made. There is a long latent period, possibly lasting decades, before the appearance of late effects. In general, only two late effects are of particular significance, the induction of neoplasms and genetic effects. That the incidence of cancer is increased by exposure to radiation is well documented. Leukemia is by far the best documented of the postirradiation cancers. However, cancers of the thyroid, breast, lung, and bone have also been linked to specific types of radiation exposure. The dose of radiation required to produce an increased incidence of cancer is not known because a population large enough to extrapolate a dose-response relationship to very low doses is not available. In human populations it is difficult or impossible. to document an increased incidence of cancer with doses of less than approximately 100 rems. It should be emphasized again that increases in the incidence of cancer result only in an increased probability of an individual developing a cancer. If the initial probability of incurring that cancer is small, then even a significant percentage increase in probability will remain a small absolute probability of incurring that cancer. There is no specific treatment for radiation-induced cancer other than that normally applied for that type of cancer; there also is no postirradiation therapy that can prevent the occurrence of cancer at a later date. It is possible, however, by the administration of iodide salts, to block uptake of radioactive iodine by the thyroid and thus possibly prevent eventual development of thyroid cancer.

The second late effect of radiation exposure of some significance is the genetic effect. Genetic effects of radiation have been demonstrated in a number of experimental systems; however, there is no clear cut documented case of a specific genetic effect of radiation in humans. Survivors of the Hiroshima and Nagasaki atomic bombings have been followed closely since their exposure and no genetic damage has been detectable in that population to date. Estimations of the doubling dose, that is, the dose of radiation necessary to double the mutation rate relative to the spontaneous rate, has produced a value of somewhere around 100 rems. Since the vast majority of mutations will be promptly lethal, however, it is unlikely that they would ever be detected because they will not produce a viable embryo. This means that even a smaller proportion of the mutations induced by radiation will ever become observed. Recessive mutations may be carried for generations before they become matched to produce the homozygous recessive individual who will express the mutation. It is apparent, however, that the fictional portrayals of massive mutational changes following radiation exposure will just not be seen and that, indeed, the long-term population effect of any such exposure will be greatly delayed and minimal.[2, 3, 11]

Management of the Radiologically Contaminated Patient

In the preceding sections I have discussed the management of the irradiated patient; that is, the patient who has been exposed to radiation but does not actually have radioactive material on or in his or her body. Irradiated patients represent no hazard to medical personnel attending them; thus, no special precautions generally need be taken to protect attending personnel. The contaminated patient, on the other hand, has on or in his body radioactive material that can act as a source of both radiation and contamination for medical personnel in attendance and for the facilities and equipment used in his treatment. It is therefore necessary to take certain protective measures to prevent the spread of radioactive contamination both to personnel and to the environment. A contaminated patient who has no other medical problems, that is, does not suffer from wounds or other trauma, presents a fairly straightforward problem in hygiene. It is necessary only to remove the contamination from the individual. This can ordinarily be accomplished by removing clothing, washing, and showering. The injured and contaminated patient, however, presents both a medical problem and a hygiene problem. This casualty will be considered in this section.

The basic rule in the management of all contaminated patients is that medical needs take priority. It accomplishes nothing to allow a contaminated patient to die of his or her injuries while one worries about the radiologic contamination. Therefore, all lifesaving and stabilizing procedures should take place immediately without regard to radiologic contamination. Even in the worst of instances it is unlikely that this will result in any substantial problems except to create a larger clean-up job. Throughout the care of the contaminated patient this rule should remain foremost.

Once the patient is stabilized or if no immediate medical treatment is necessary, decontamination should be initiated by removal of any obvious heavy contamination. This step will ordinarily have been taken at the site of the accident or on route to the hospital. If it has not, all clothing should be removed, preferably by cutting away, and retained in large plastic bags. Areas of obvious contamination, such as those that appear to be "dirty," should have the contamination brushed away or wiped away. At this point the patient should be surveyed for contamination and a body diagram should be used to indicate contaminated areas and the meter readings for each (Fig. 2). Body orifices, including the ears, nares, and mouth, should be monitored by taking swipes. Cotton tip applicators can be used, but swipes are better done by wrapping a strip of absorbent filter paper around the end of an applicator stick and dampening the paper slightly. This can be inserted into the areas to be monitored, rotated gently, and removed. When dried, these filter paper strips can be counted for radiologic contamination. During the decontamination procedure, all materials used in the decontamination, including wash water, should be retained for counting. If there is widespread contamination over the body surface and if the medical condition warrants, a tepid shower with a good lathering soap will be effective in removing most of the contamination. Hair should be shampooed with a mild shampoo. Should contamination be present within the external ear canals, the nose, or the mouth, these areas can be mildly irrigated, although precautions should be taken to prevent ingestion of any irrigation fluid. Blowing of the nose and snipping the hair in the nares is frequently adequate to remove the majority of nasal contamination.

Following initial decontamination, the body should be resurveyed and measurements once again recorded on an outline diagram. Areas continuing to show levels of contamination should be rewashed repeatedly until no further reduction in contamination can be made, that is, radiation measurements can be no further reduced. At this point it may be possible to remove a small amount of additional contamination by scrubbing gently with a very soft bristle brush, taking care not to abrade the skin. No drastic measures should be taken for the removal of contamination. Small amounts remaining on the skin are generally innocuous. Areas in which such contamination remains can generally be further decontaminated by covering with an occlusive dressing or Dermaplast for a day. Normal sloughing of the skin

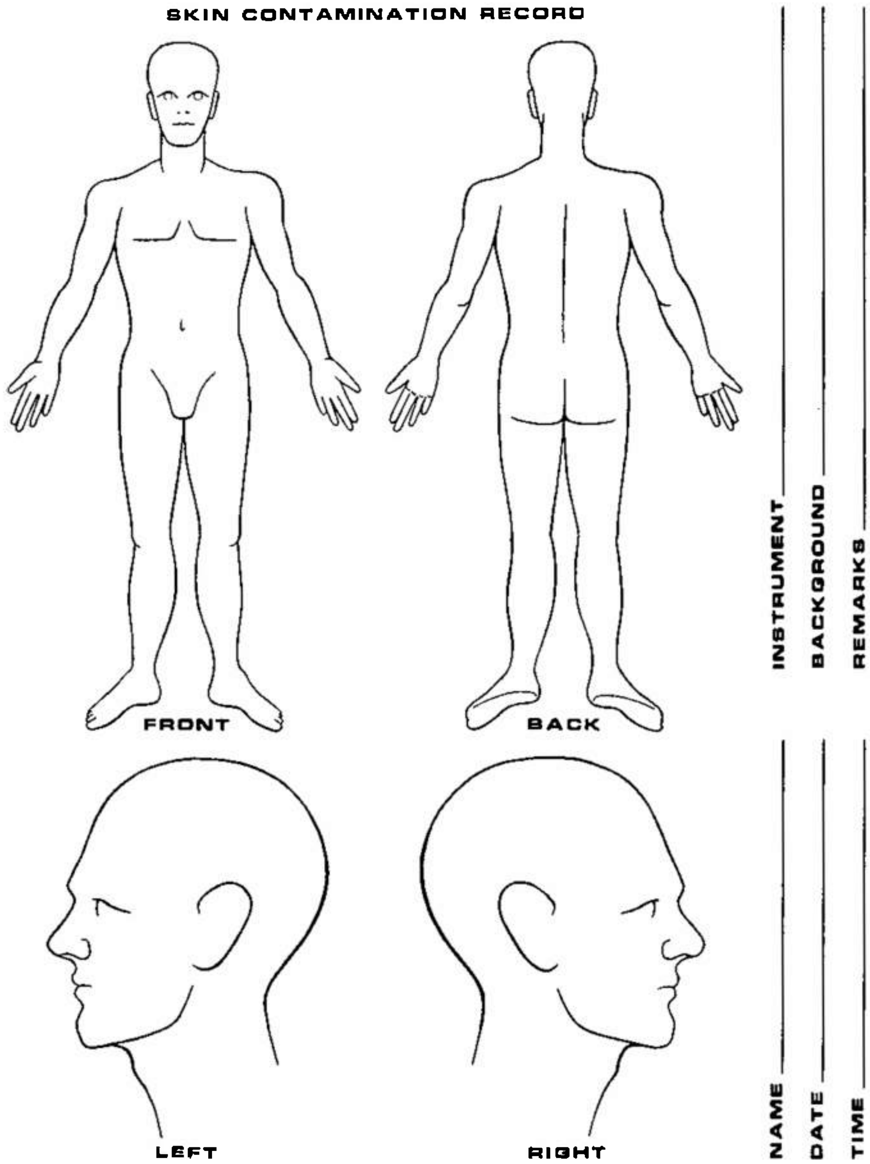

Figure 2. A diagram such as this can be used as a skin contamination record.

when the dressing is removed may result in removal of additional contamination.[4, 6–10]

Decontamination of Wounds. There is some degree of controversy as to whether wounds should be decontaminated prior to or after decontaminating the skin. For very light contamination it is probably satisfactory to initally irrigate the wound, allowing the washing to flow over the surrounding skin. When the wound is adequately decontaminated, it can be covered while the skin is decontaminated. For heavier levels of wound contamination, it is probably best to first decontaminate the rest of the body and surrounding skin. At this point, the skin surrounding the wound can be covered with a self-adhering surgical drape and thorough decontamination of the wound can take place. As with decontamination of the skin, frequent monitoring of the wound between decontamination efforts should be made and all readings recorded. Any obvious large pieces of contaminating material can be removed physically. It may be possible to remove additional pieces using a magnetic probe if the material lends itself to such action. Flushing with copious amounts of irrigation water, all of which should be retained for radiation measurement, and mild stimulation of bleeding will remove a great deal of wound contamination. Use of hydrogen peroxide as an effervescent agent is very effective in removing foreign material from the wound and also acts well as a disinfecting agent. If, following these procedures, contamination remains within the wound, a minimal amount of debridement should be carried out. This should not exceed removal of obviously nonviable tissue. Any tissue removed should be retained for later monitoring. Likewise, all contaminated instruments should be carefully monitored before cleaning. It is unnecessary to take drastic measures to remove contamination from the wound when the level is reached at which further contamination cannot be removed by the means that have been described. Normal medical treatment of the wound should then take place. If a significant amount of contamination has been retained in the wound, it should be dressed open for a 24-hour period. During this time bleeding and exudate into the wound will free up much of the remaining contamination, which may then be removed by debridement.[9]

Decontamination of Internally Contaminated Individuals. If during the initial monitoring for contamination the patient is found to have significant contamination of the mouth, nose, or pharynx, it can be assumed that some radioactive material has been inhaled or ingested. Initial efforts should be made to clear the oral and nasal cavity and pharynx of any remaining material, with care being taken to avoid having the patient swallow or inhale any additional material. Removal of inhaled radioactive material beyond this point is extremely difficult, potentially hazardous, and probably not warranted except under unusual conditions, and then only by an appropriate specialist. Consultation with the REAC/TS organization is recommended in this case. Of any inhaled material, only about one-eighth will remain within the lungs after 24 hours. The remainder will be removed by the normal pulmonary clearing mechanisms; the majority of this will be swallowed and will constitute ingestion contamination. For ingested radioactive materials, initial efforts should be to remove as much material as possible from the stomach. It is recommended that this be done by inducing vomiting and, again, retaining all material for later monitoring. Gastric intubation and lavage may be used, but it is not recommended except on the advice of an appropriate specialist. Absorption of radioactive material can be minimzed by the use of activated charcoal and antacids, which reduce absorption of acid-soluble materials. Administration of magnesium sulfate or other precipitating agents can also be used to form less soluble compounds that will then pass through the gastrointestinal tract unabsorbed. Elimination of gastrointestinal contamination can be hastened by administration of cathartics. Magnesium sulfate is probably the agent of choice in this regard, in that it not only acts to speed gastrointestinal elimination but serves to precipitate out some materials. All fecal material should be retained for monitoring. The use of chelating agents such as ethylenediamine tetracetic acid (EDTA) or diethylenetriamine pentaacetic acid (DTPA) is not recommended except with the specific advice of a radiation medicine specialist. These agents are of value almost exclusively in the treatment of contamination with transuranic elements and are themselves dangerous to use. These agents may be provided for treatment by REAC/TS when indicated and under the direction of their medical specialists. They are not ordinarily available for routine use.

To summarize, the managment of radiologically contaminated patients should be primarily concerned with good medical care. All lifesaving measures should take precedence over concerns about radiation contamination. Decontamination is primarily a function of good hygiene and can be carried out for the most part by gentle cleansing. Frequent monitoring of the remaining radiation levels is essential to keep track of progress in decontamination. Small amounts of remaining contamination are, for all practical purposes, innocuous and can be left. Drastic measures should not be taken to effect decontamination. In no event should any potentially disfiguring or disabling procedures be taken in order to effect decontamination.[9]

RADIATION ACCIDENT PROTOCOL

Every hospital emergency department should have prepared a protocol for the management of radiation accident victims. Since no single protocol fits all circumstances and because numerous sample protocols have been published and are available, no attempt will be made to develop a specific protocol in this article. Rather, consideration of the factors involved will be discussed. This will include the people, the place, and the equipment and supplies necessary; specific procedures to be carried out can be derived from the preceding sections of this paper. A listing of sample protocols is provided.[4, 6–10]

People

The head of the radiation accident team should be a physician, preferably a surgeon or other physician qualified in emergency care. At a minimum, certification in advanced trauma life support should be a requirement. An emergency nurse should also be assigned to the team to be responsible for set up of the facility, collecting specimens, and assisting the physican. A radiation safety officer is also a requirement. Ideally, this would be a health physicist from the radiology department. However, a radiologist, an x-ray technician, or a nuclear medicine technician could serve in this capacity, provided that the individual were trained in radiologic monitoring. A number of attendants should also be specifically assigned. These would include one to assist the physician in charge in carrying out medical procedures, one to perform decontamination, and one to serve as the control point monitor. Additional personnel as necessary and available should be assigned.[4, 6–10]

Place

The ideal location for a radiation accident treatment facility is immediately adjacent to the hospital emergency department. This is not always possible and the best arrangement allowed by the circumstances should be made. It is inefficient to provide an area for this purpose that has no other use and doing so is discouraged unless such an area has been provided by a nuclear power plant or other facility in the area. It is much better for the average hospital to assign a dual purpose area to this function. It may be one room within the emergency department that manages normal emergency cases under ordinary conditions. Many hospitals have established radiation treatment facilities within the morgue. This has the advantage that the equipment available generally lends itself to containment of contamination. An idealized radiation casualty treatment facility is shown in Figure 3. An area such as this can easily serve as on-call quarters for staff, normal rest rooms, or even a lounge when it is not needed for radiation treatment capability. Note that the facility has a one-way patient flow from areas of higher contamination to areas of lower contamination

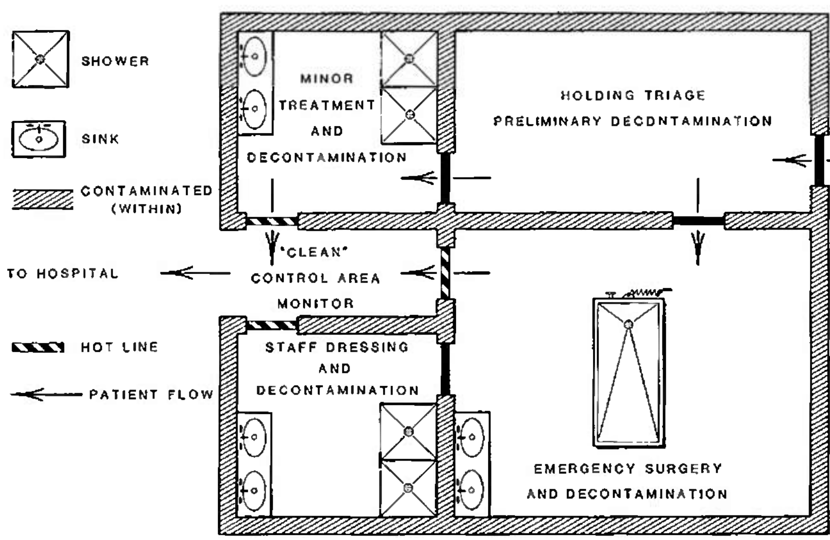

Figure 3. An idealized radiation casualty treatment facility is shown.

and an easily managed control point for individuals passing into clean areas. In addition, staff access does not need to cross the patient flow lines.[4, 6–10]

Equipment and Supplies

The radiation casualty treatment facility should be provided with medical supplies, as would any other emergency treatment facility, at least to the capability of providing advanced trauma life support. The equipment provided should include rolls of plastic or paper for covering the floor areas within the contamination area (sheets are an acceptable substitute for this). An ideal covering is one that provides a waterproof plastic laminated to an absorbent material that is spread with the plastic side down. A "clean floor" can be made within the contamination area by rolling fresh covering across contaminated covering to permit decontaminated patients access to the hot line for monitoring and entry into the clean area. Several rolls of tape should be available for use in marking off clean from contaminated areas, as well as to be used for protecting surfaces from contamination. This tape can also be used to mark off routes of entry and egress and for mounting radiation signs, which should also be available. Radiation monitoring equipment is necessary and should consist of one or two beta-gamma detectors. A separate alpha detector is valuable but is not essential unless a specific need is known to exist. A number of containers in various sizes should be available for holding the contaminated specimens, along with radioactive labels to mark the containers. Radiation dosimeters should be available for all personnel who will take part in the decontamination procedures as well as extras to be used as area monitors within the facility. Preferably, dosimeters of two types should be available for each individual; one of the permanent type such as the film badge or thermoluminescent dosimeter and one direct reading pocket dosimeter for on-the-scene monitoring. It also may be of value to have ring dosimeters available for use on the fingers of individuals decontaminating wounds to determine the local radiation dose. Anticontamination clothes should be available for all personnel within the facility. Surgical scrub suits work perfectly well for this purpose. In addition to scrub suits, surgical gowns, hoods, masks, booties, and a variety of surgical gloves should be available. Dressing as one would for a surgical operation should provide more than adequate protection. If a particularly heavy contamination is expected, double suiting and wearing of a waterproof apron will provide additional protection.

A treatment table that can also serve as a decontamination table should be available. It should be in the nature of a shallow tub with a drain located at one end running to a container for retaining wash water. The patient can be decontaminated directly in the tub and have his or her wounds cared for on the table. Plastic trash bags, large waste containers, and water containers should be available for retaining all waste water and cleaning supplies. Patient outline charts for recording levels of contamination should be on hand. Several soft scrub brushes, mild soap or detergent, and a mixture of corn meal and detergent should be available for use in decontamination, as well as a bottle of 3 per cent hydrogen peroxide. It is essential for all involved to be carefully trained in the containment of radiologic contamination and that all understand how to remove their own contaminated clothing and to decontaminate themselves. The need to prevent the spread of contamination outside of the radiation treatment facility should be stressed.[4, 6–10]

Public Relations Aspects

A radiation accident will promptly generate intense interest, and queries by the press may adversely affect casualty management. To obviate such problems, all statements regarding care of accident victims should come from or pass through the hospital's public relations office. Comments regarding the accident or public health hazards should come from the overall incident commander. All hospital personnel should be directed to refer all media inquiries to the public relations office. Patient confidentiality should always be maintained. Any information provided should be factual and straightforward; providing periodic statements may eliminate many of the untimely queries. References to radiation exposures should be illustrated in simple terms, such as comparing them to the radiation from a chest x-ray or some other procedure that will be readily understood by the public. It is essential that all members of the hospital staff appear to be calm and knowledgeable about the situation to avoid even the slightest suggestion of panic. It may be useful to have a prepared press release format that requires only filling in blanks. This will allow a prompt response to initial press queries and promulgate an image of control. Additional statements can then be prepared as the situation develops and additional information becomes available.

Psychological Considerations

As pointed out in the introduction, perhaps nothing excites as much fear in people as the prospect of a "radiation," "nuclear," or "atomic" accident. In fact, this fear is based primarily on the basic human fear of the unknown and, to a large extent, is exacerbated by a good deal of misinformation. This fear has, in some cases, resulted in denial of care to radiation accident victims by health care facilities. In at least one case known to me, the victim of a lethal radiation exposure not involving any contamination was turned away from more than one facility because the facilities claimed to be unprepared to care for a radiation accident victim.

This basic fear should be taken into account in the management of any radiation accident. The psychological status of the accident victim(s), the hospital staff, and the general public must all be considered. This is best done by providing adequate, understandable information and knowledgeable reassurance. Adequate training of the staff in advance of any accident is most important in psychologically preparing them for receiving the victim of a radiation accident. This training should include not only those involved in direct care and decontamination of the victim but also the remainder of the staff, especially support personnel who may be affected by the knowledge that a radiation accident victim is in the hospital.

Training

An adequate training program is essential to an effective radiation accident management team. Initial and refresher training should be pro-

Table 4. *Training Sources and Training Aids*

1. American Occupational Medical Association 2340 S. Arlington Heights Road Arlington Heights, Illinois 60005 *Periodically sponsors post-graduate training seminars. May also serve as a source of speakers for locally sponsored programs.*
2. Radiation Accident Preparedness Medical and Managerial Aspects Eugene L. Saenger, M.D.; Gould A. Andrews, M.D.; Roger E. Linnemann, M.D., and Neil Wald, M.D. Sponsored by Edison Electric Institute Produced and distributed by Science-Thru-Media, Inc. 305 Fifth Avenue, Suite 803 New York, New York 10016 *A series of taped lectures with text and self-assessment examination providing CME/I credit.*
3. Radiation Emergency Assistance Center/Training Site (REAC/TS) Oak Ridge Associated Universities Post Office Box 117 Oak Ridge, Tennessee 37830 *REAC/TS provides a series of excellent courses in handling radiation accidents for physicians, nurses, health physicists and EMTs. REAC/TS has recently completed a set of videotapes for the Federal Emergency Management Agency (FEMA) for use in training packages currently in preparation. These packages should be ready for distribution in the very near future.*
4. Training Resources, a division of Nuclear Support Services, Inc. Suite B-3, 9150 Rumsey Center Columbia, Maryland 21045 *Excellent slide programs for use in in-house training.*

vided in all levels—professional, technical, and support. In addition, orientation sessions should be provided for all personnel who are not directly involved in the team. Some outside formal training will be necessary for selected individuals in order to develop a knowledgeable core, but the majority of the training can be provided in-house using available trained staff. A listing of some available training sources and training aids is shown in Table 4.

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